Comparative Height Growth to Age 28 for Seven Species in the CWHd Subzone

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ABSTRACT

Height growth curves to age 28 are developed from remeasurement of 49-tree permanent plots planted with Douglas-fir, grand fir, amabilis fir, Port-Orford cedar, Sitka spruce, western hemlock, and western redcedar on a moist and nutrient-medium site within the Hypermaritime Coastal Western Hemlock (CWHd) subzone on the west coast of Vancouver Island, British Columbia. Douglas-fir had the best height growth, followed in turn by Sitka spruce, western hemlock, grand fir, Port-Orford cedar (the only non-indigenous species), western redcedar, and amabilis fir. However, the growth of these species on other sites within the CWHd subzone should be interpreted cautiously, since this study appears to be on a unique soil type. The height growth curves conform in shape with the height curves published in the Pacific Northwest and the U.K. Forestry Commission. These curves provide the only basis for comparing the growth of six indigenous species on Vancouver Island and for providing a measure of early height growth.

Keywords: Juvenile height growth; reforestation; CWHd subzone; comparative height growth; age to breast height.

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TABLE OF CONTENTS

ABSTRACT iii
ACKNOWLEDGEMENTS iii
INTRODUCTION 1
METHODOLOGY 1
Study Area 1
Experiment Design and Establishment 1
Analysis 3
RESULTS 4
DISCUSSION 8
CONCLUSIONS 8
REFERENCES 9

TABLES

1 EP 368 seed source by species 2
2 EP 368 plot assessment and maintenance 2
3 Height-age data summaries for seven coniferous species in EP 368 4
4 Juvenile height growth curves coefficients 4

FIGURES

1 EP 368 design and layout 2
2 Height growth curves (total age) for seven coniferous species in EP 368 5
3 Height growth curves (breast-height age) for seven coniferous species in EP 368 5
4 Comparison of Sitka spruce height growth curves 5
5 Comparison of western hemlock height growth curves 5
6 Comparison of western redcedar height growth curves 6
7 Comparison of Port-Orford cedar height growth curves 6
8 Comparison of amabilis fir height growth curves 6
9 Comparison of grand fir height growth curves 6
10 Comparison of Douglas-fir height growth curves 7

INTRODUCTION

In reforestation, knowledge of the height growth performance of young stands within well-defined ecosystem units is of considerable interest. Such knowledge is useful for the site-specific estimation of height growth on cutover areas, and for the evaluation of early stand growth in plantations. It could also have a significant impact on tree species selection.

Experimental Project (EP) 368 of the British Columbia Ministry of Forests and Lands, Research Branch, provides a unique opportunity to compare the juvenile height growth of Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco), grand fir (*Abies grandis* [Dougl. *ex* D. Don] Lindl.), amabilis fir *(Abies amabilis* [Dougl. *ex* Land.] Forbes), Port-Orford cedar *(Chamaecyparis lawsoniana* [A. Murr.] Port.), Sitka spruce (*Picea sitchensis* [Bong.] Carr.), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), and western redcedar (*Thuja plicata* Donn) on a moist and nutrient-medium site within the Hypermaritime Coastal Western Hemlock (CWHd) subzone (Klinka *et al.* 1984.) on the west coast of Vancouver Island. Similar height growth comparisons have been made in some sites in coastal British Columbia (see Walters and Haddock 1966; Omule and Krumlik 1987[1]); however, for species comparisons within the CWHd subzone, EP 368 is the only data source so far.

METHODOLOGY

STUDY AREA

Experimental Project 368 was established by the B.C. Ministry of Forests and Lands in 1958 about 8 km north of Ucluelet on the west coast of Vancouver Island. The objective of the study was to compare the growth of seven coniferous species planted on a common site. Except for Port-Orford cedar,all the species tested are indigenous to Vancouver Island.[2] The study area, located within the CWHd subzone, initially supported old-growth stands of western hemlock, amabilis fir, and western redcedar. The area was logged in 1955 and slashburned (to an unknown extent) in autumn 1957. The soil is classified as orthic Humo-Ferric Podzol (Canadian Soil Survey Committee 1978), with a Lignohemimor humus layer. It is a gravelly, sandy loam, well drained, with a rooting depth of over 90 cm. The soil moisture and nutrient regime is moist and nutrient-medium.[3] The Douglas-fir site index is estimated at about 34 m at 50 years breast-height age, based on Bruce's (1981) site curves.

The climate near the study area is cool, wet,and foggy in the summer, and mild in the winter, with a mean annual precipitation of 3120 mm (Klinka *et al.* 1984, p. 38).

EXPERIMENT DESIGN AND ESTABLISHMENT

The experiment was planted in a randomized complete block with seven tree species, each replicated seven times (Figure 1). Each replicate (plot) consisted of 49 trees planted at approximately 8 ft (2.44 m) spacing. There are no buffers. The plots were planted in spring 1958 with 2+0 bareroot stock which was raised in the same nursery from seed of unknown seedlot numbers (Table 1). Since then, the plots have been maintained and remeasured at 1- to 6-year intervals (Table 2). In the 1975 assessment, no heights were measured; in the 1984 assessment only a subsample of trees was measured for height; in all other assessments where heights were measured, all trees in a plot were included.

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1 Omule, S.A.Y. and G.J. Krumlik. 1987. Juvenile height growth for Douglas-fir, western hemlock, Sitka spruce and western redcedar in four sites on the west coast of Vancouver Island. B.C. Min. For. Lands, Res. Branch. Review Manuscript.

2 A more detailed account of the study is given in the 1987 progress report on EP 368 by S.A.Y. Omule, B.C. Min. For. Lands, Res. Branch, Victoria, B.C.

3 The soil and vegetation descriptions were conducted by G.J. Krumlik, B.C. Min. For. Lands, Res. Branch, 1983.

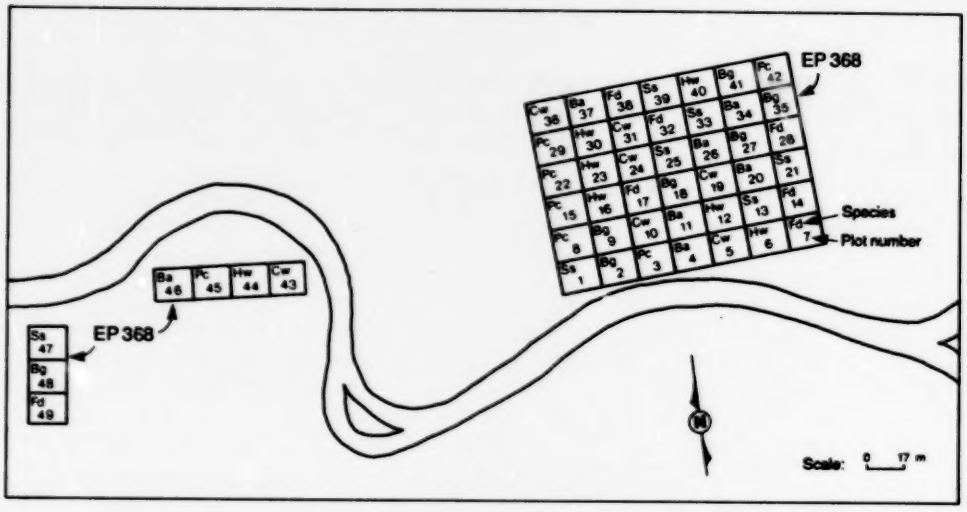

FIGURE 1. EP 368 design and layout.

TABLE 1. EP 368 seed source by species

Tree Species	Seed source[a] Location	Elevation
Douglas-fir	Caycuse	unknown
Grand fir	Courtenay	unknown
Pacific silver fir	Bear Creek (near San Juan River)	3000 ft. (914 m)
Port-Orford cedar	Southern Oregon	unknown
Sitka spruce	East Sooke	unknown
Western hemlock	East Sooke	unknown
Western redcedar	Bear Creek (near San Juan River)	3000 ft. (914 m)

[a] The seedlot numbers are unknown.

TABLE 2. EP 368 plot assessment and maintenance

Date	Total age (yrs.)	Maintenance/ treatment	Assessment Survival	dbh[a]	Height	Plot numbers
4/1958	2	planted				1-49
9/1958	3		X			1-7
9/1959	4		X		X	1-49
8/1960	5		X		X	1-7
9/1961	6		X		X	1-7
9/1962	7		X		X	1-14
9/1963	8			X	X	1-14
6/1965	9			X	X	1-14
8/1970	15	weeded[b] and pruned[c]		X	X	1-49
8/1975	20	cleaned[d]		X		1-45
5/1978	22	thinned[e]		X	X	1-49
6/1984	28	cleaned[d]		X	X	1-49

[a] dbh = diameter at breast height (4.5 ft.; 1.37 m) outside bark.
[b] Weeding involved cutting coniferous regeneration as well as non-coniferous vegetation within an approximate 1-m radius from each tree. Natural regeneration of western hemlock and western redcedar was left as fill-in in the plots with poor survival. Twin or multiple stems were cut.
[c] The trees were all pruned to about 7 ft. (2.1 m) above ground.
[d] All coniferous regeneration was cut; salal and other lesser vegetation not cleared.
[e] The plots were thinned to about 800 stems per hectare with d/D ratio of .7-1.0.

Measurements made prior to 1975 were taken in imperial units and subsequently converted to metric before analysis.

ANALYSIS

Juvenile height growth curves were developed for each tree species as follows:

First, unmeasured tree heights in 1984 were estimated from appropriate height-diameter curves fitted separately for each plot. Tree heights in 1975 were estimated by linear interpolation between the 1970 and 1978 height and diameter measurements as follows:

$$\text{tree height in 1975} = h_{70} + (dbh_{75} - dbh_{70}) * \frac{h_{78} - h_{70}}{dbh_{78} - dbh_{70}}$$

where

h_{70} and h_{78} are the tree heights in 1970 and 1978, respectively, and dbh_{70}, dbh_{75} and dbh_{78} are the tree diameters in 1970, 1975, and 1978, respectively.

Next, for measurements from 1970 onwards, top height was calculated for each plot as the arithmetic average total height (measured or estimated) of the 100 trees per hectare (3 trees per plot) of largest diameter. For measurements prior to 1970, the average height of the tallest four trees per plot was calculated. All the survivor trees in a plot were considered without regard for possible edge effects. (Preliminary comparisons at age 22 – when all trees were measured for height – showed no significant differences in height between the outer and inner trees, suggesting that the lack of buffers had a negligible effect on top height). The constitution of the "top height subsample" changed over time: on the average, only about one out of three trees per plot consistently remained in the subsample between ages 15 and 28.

A height growth curve was then developed by regressing top height against total age from seed, for each species, using the following model:

$$\ln(y) = a + b*\ln(x) + c*\ln^2(x) \qquad (1)$$

where

y = top height in metres

x = total age from seed in years.

Model (1) was fitted by ordinary linear least squares, and the resulting curves compared among species using parallelism and coincidence tests (Kozak 1970). The fitted growth curves were graphically compared with those from the U.K. Forestry Commission (Hamilton and Christie 1971), and with some published in the Pacific Northwest for Douglas-fir (Bruce 1981), Sitka spruce (Barker 1983[4]), western hemlock (Wiley 1978), western redcedar (and Port-Orford cedar) (Kurucz 1978), and amabilis fir (and grand fir) (Kurucz 1986).

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4 Barker, J.E. 1983. Site index relationships for Sitka spruce, western hemlock, western redcedar and red alder in Moresby Tree Farm Licence #24, Queen Charlotte Islands. File progress report, Western Forest Products Ltd., Vancouver, B.C.

RESULTS

Using the height-age data for each species (summarized in Table 3), height growth equations were developed (Table 4), depicted graphically by species, and visually compared with the U.K. Forestry Commission curves and those published in the Pacific Northwest (Figures 2-8).

After 28 years, Douglas-fir had the best height growth, followed in turn by Sitka spruce, western hemlock, grand fir, Port-Orford cedar, western redcedar, and amabilis fir (Figures 9 and 10). Although the height growth of amabilis fir was poorest, it is beginning to increase rapidly. The height growth of western hemlock appears to decline after age 20 (Figure 9). The data also show that different species reached breast height (1.30 m) at different ages as follows: about 4 years for Douglas-fir, Sitka spruce, western hemlock, and Port-Orford cedar; about 5 years for grand fir and western redcedar; and about 8 years for amabilis fir (Figure 9).

The height growth curves of all the species to age 28 generally conformed in shape with the height curves of the U.K. Forestry Commission and some published in the Pacific Northwest (Figures 2-8).

TABLE 3. Height-age data summaries for seven coniferous species in EP 368[a]

Age[b] (years)	Average top height (m) Tree species						
	Ba[c]	Bg	Fd	Hw	Pc	Cw	Ss
4	.3	0.9	1.5	1.2	1.4	0.9	1.3
5	.5	1.2	2.0	1.7	1.5	1.0	1.8
6	.6	1.8	3.0	2.8	2.4	1.5	2.7
7	1.0	2.5	4.0	3.7	3.0	2.1	3.6
8	1.7	3.1	4.5	4.5	3.6	2.8	4.0
15	4.9	7.1	9.3	9.1	6.7	6.1	8.8
20[d]	7.5	10.1	14.2	12.8	9.6	9.0	12.7
22	8.4	10.8	15.4	13.7	10.1	9.7	14.7
28	12.0	15.9	20.2	16.9	14.3	12.2	19.9

a The averages are based on seven plots per species.
b Total age from seed.
c Ba = Pacific silver fir
Bg = Grand fir
Fd = Douglas-fir
Hw = Western hemlock
Pc = Port-Orford cedar
Cw = Western redcedar
Ss = Sitka spruce
d Heights estimated by interpolation between ages 15 and 22 measurements.

TABLE 4. Juvenile height growth curves coefficients[a]

Tree species	a	b	c	SEE[b]	r^2	cv[c]	No. of meas.
Douglas-fir	−2.65957	2.38125	−0.20563	0.09913	.99	5.0	41
Grand fir	−3.86968	2.94175	−0.28659	0.11292	.99	6.8	34
Amabilis fir	−5.91253	3.86108	−0.40513	0.17019	.99	14.9	38
Port-Orford cedar	−1.83913	1.60442	−0.07987	0.10387	.99	5.8	37
Sitka spruce	−2.45248	2.14719	−0.15713	0.08551	.99	4.3	38
Western hemlock	−3.04079	2.78565	−0.30560	0.07026	.99	3.6	35
Western redcedar	−2.51215	1.94110	−0.12623	0.08691	.99	5.4	35

a The linear model $\ln(y) = a + b*\ln(x) + c*\ln^2(x)$ was fitted by ordinary linear least squares; y = top height in metres and x = total age from seed in years.
b SEE = Estimate of the standard deviation of ln (y) around the regression line.
c cv = coefficient of variation: SEE as a percentage of the mean of ln (y).

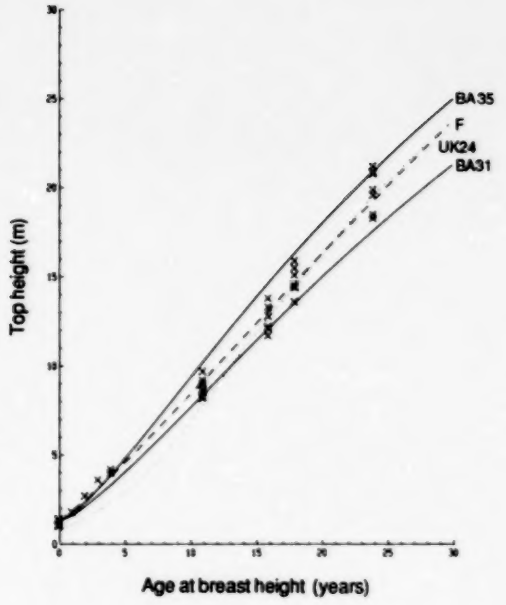

FIGURE 2. Comparison of Sitka spruce height growth curves. X = EP 368 raw data; F = EP 368 fitted curve; UK24 = U.K. Forestry Commission curve for yield class 24; BA31, BA35 = Barker (1983) site curves: 31 and 35 m, respectively, at breast-height age 50.

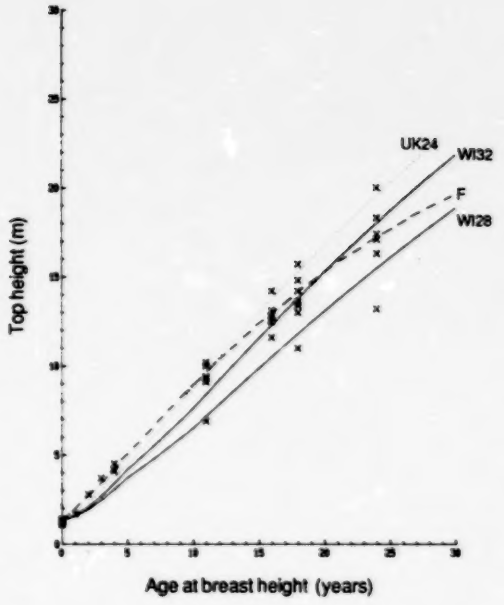

FIGURE 3. Comparison of western hemlock height growth curves. X = EP 368 raw data; F = EP 368 fitted curve; UK24 = U.K. Forestry Commission curve for yield class 24; WI28, WI32 = Wiley (1978) site curves: 28 and 32 m, respectively, at breast-height age 50.

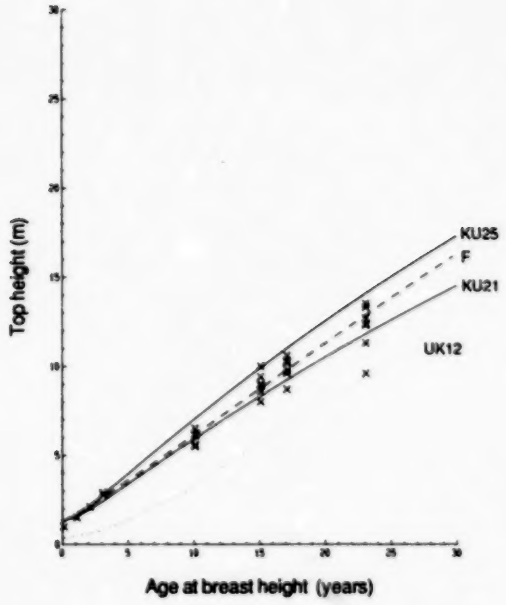

FIGURE 4. Comparison of western redcedar height growth curves. X = EP 368 raw data; F = EP368 fitted curve; UK12 = U.K. Forestry Commission curve for yield class 12; KU21, KU25 = Kurucz (1978) site curves: 21 and 25 m, respectively, at breast-height age 50.

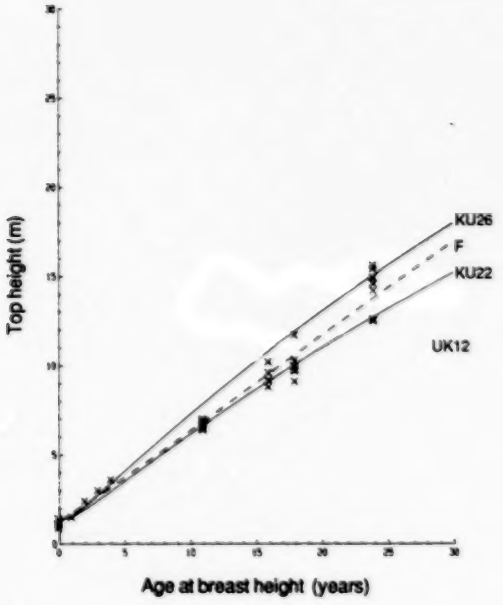

FIGURE 5. Comparison of Port-Orford cedar height growth curves. X = EP 368 raw data; F = EP 368 fitted curve; UK12 = U.K. Forestry Commission curve for yield class 12; KU22, KU26 = Kurucz (1978) western redcedar site curves: 22 and 26 m, respectively, at breast-height age 50.

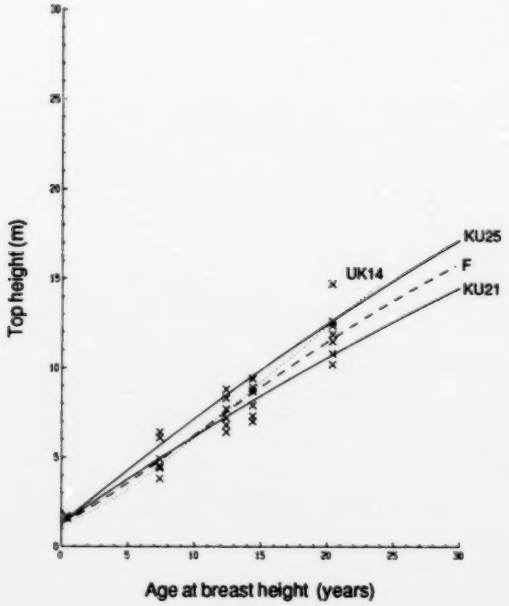

FIGURE 6. Comparison of amabilis fir height growth curves. X = EP 368 raw data; F = EP 368 fitted curve; UK14 = U.K. Forestry Commission curve for yield class 14; KU21, KU25 = Kurucz (1978) site curves: 21 and 25 m, respectively, at breast-height age 50.

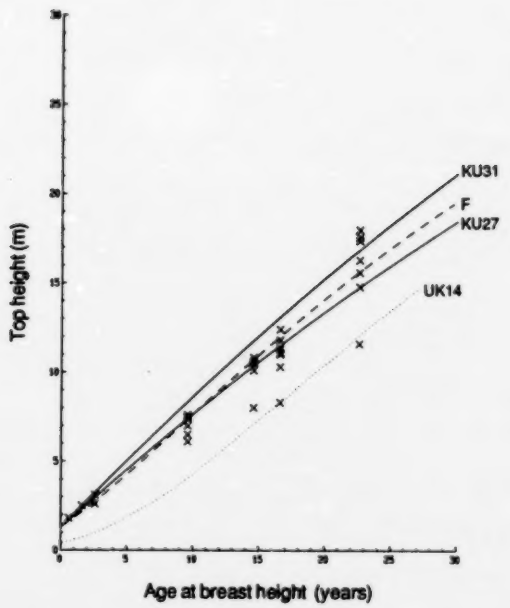

FIGURE 7. Comparison of grand fir height growth curves. X = EP 368 raw data; F = EP 368 fitted curve; UK14 = U.K. Forestry Commission curve for yield class 14; KU27, KU31 = Kurucz (1986) amabilis fir site curves: 27 and 31 m, respectively, at breast-height age 50.

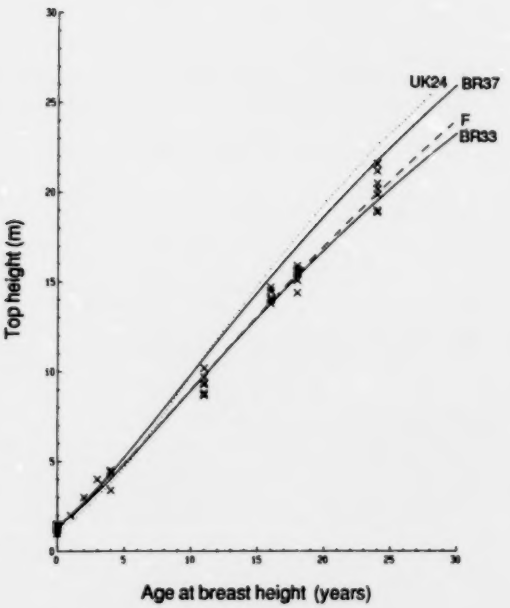

FIGURE 8. Comparison of Douglas-fir height growth curves. X = EP 368 raw data; F = EP 368 fitted curve; UK24 = U.K. Forestry Commission curve for yield class 24; BR33, BR37 = Bruce (1981) site curves: 33 and 37 m, respectively, at breast-height age 50.

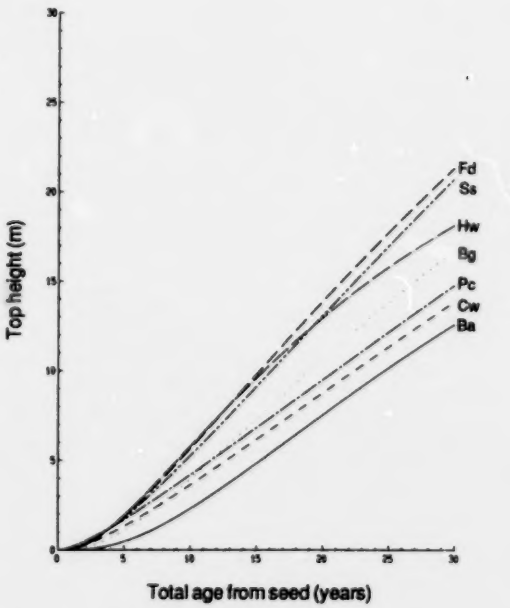

FIGURE 9. Height growth curves (total age) for seven coniferous species in EP 368. Ba = amabilis fir; Bg = grand fir; Cw = western redcedar; Fd = Douglas-fir; Hw = western hemlock; Pc = Port-Orford cedar; Ss = Sitka spruce.

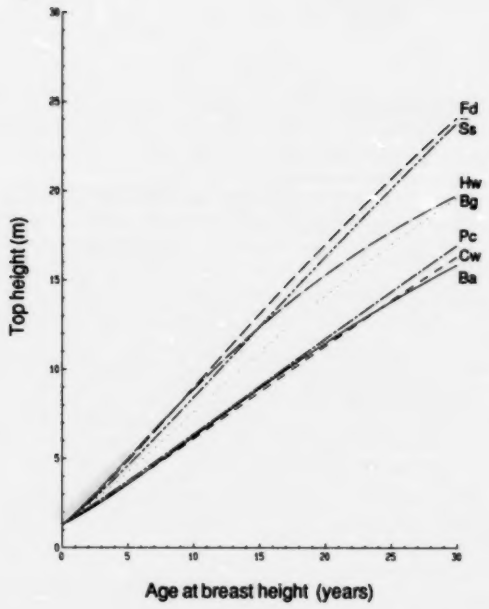

FIGURE 10. Height growth curves (breast-height age) for seven coniferous species in EP 368. Ba = amabilis fir; Bg = grand fir; Cw = western redcedar; Fd = Douglas-fir; Hw = western hemlock; Pc = Port-Orford cedar; Ss = Sitka spruce.

DISCUSSION

In general, the height growth to age 28 reflects expected relationships between the site and species. For example, both grand fir and amabilis fir grow slowly at first, but then increase rapidly over time (see, for example, Harrington and Murray 1981, p. 209). Pest damage had not affected the height growth of any of the tree species, notably Sitka spruce, which has not been attacked by the spruce weevil (*Pissodes strobi* Peck.).

It is difficult to say how respresentative these results are of the operationally maintained plantations on similar sites within the same area. For example, operationally planted Douglas-fir trees near the study area generally exhibited stem lumpiness and large branches (Carter and Klinka 1986), unlike the trees in this study. Provenance, soil type, and perhaps pruning may have improved the stem form and branches of these trees.

Although the height growth curves of all the species to age 28 conform in shape to published height curves, the advantage is that the curves here have been developed on a site-specific basis, enabling more site-specific decision-making. The main potential uses of these growth curves (Figure 9) are: 1) in developing standards for an objective evaluation of early stand growth; and 2) in estimating height growth on cutover areas from indicator plant species and/or soil factors. The early growth trends may also have an impact on tree species selection, and may point out the advantage of getting the trees to breast height in reforestation.

CONCLUSIONS

The results for the species and site and stand conditions in this study indicated that:

-Douglas-fir was taller than all other species, followed in turn by Sitka spruce, western hemlock, grand fir, Port-Orford cedar, western redcedar, and amabilis fir; the average top heights at total age 28 years were: 20.2, 19.9, 16.9, 15.9, 14.3, 12.2, and 12.0 m, respectively.

-Douglas-fir, Sitka spruce, western hemlock, and Port-Orford cedar reached breast height (1.3 m) in about 4 years, grand fir and western redcedar in about 5 years, and amabilis fir in about 8 years.

-The tree species did not exhibit any significant stem form defects, and were free of pest damage.

-The height growth curves of all the species to age 28 generally conformed in shape to some of the curves published in the Pacific Northwest and the U.K. Forestry Commission.

The growth of these species on other sites within the CWHd subzone should be interpreted cautiously, however, since this study appears to be located on a unique soil type. These height growth curves provide the only basis for comparing the growth of six indigeneous species on Vancouver Island, and for providing a measure of early height growth.

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